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Long-term Global Morphology of Gravity Wave Activity Using UARS Data

Contract NAS5-98045

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Quarterly Report

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1. Work and Results this Quarter

1.1 Analysis of Small-scale CRISTA Temperature Variances

In collaboration with scientists at the University of Wuppertal, Germany, we continued research on the reduction, analysis and interpretation of high-resolution temperature profiles from the Cryogenic Infrared Spectrometers and Telescopes for the Atmosphere (CRISTA¹) instrument. We started analyzing data from both missions this quarter. In the first mission, the CRISTA-SPAS satellite was deployed by Atlantis on November 3, 1994 and retrieved ~8 days later². During the second mission, CRISTA-SPAS was deployed by Discovery on August 7, 1997 and retrieved on August 16 [Offermann and Conway, 1995]. Figure 1 shows new results for the temperature variance measured by CRISTA during the second mission. The data show interesting similarities to data obtained during the first mission (see Plate 1 of previous report). These include large variances in the equatorial belt, and bursts of variance near the southern tip of South America and near the Russia-China region. Interesting additional features occur here: e.g., bursts of variance over the Southern

CRISTA Temperature Variance: August 9-13, 1997: Height 23 km

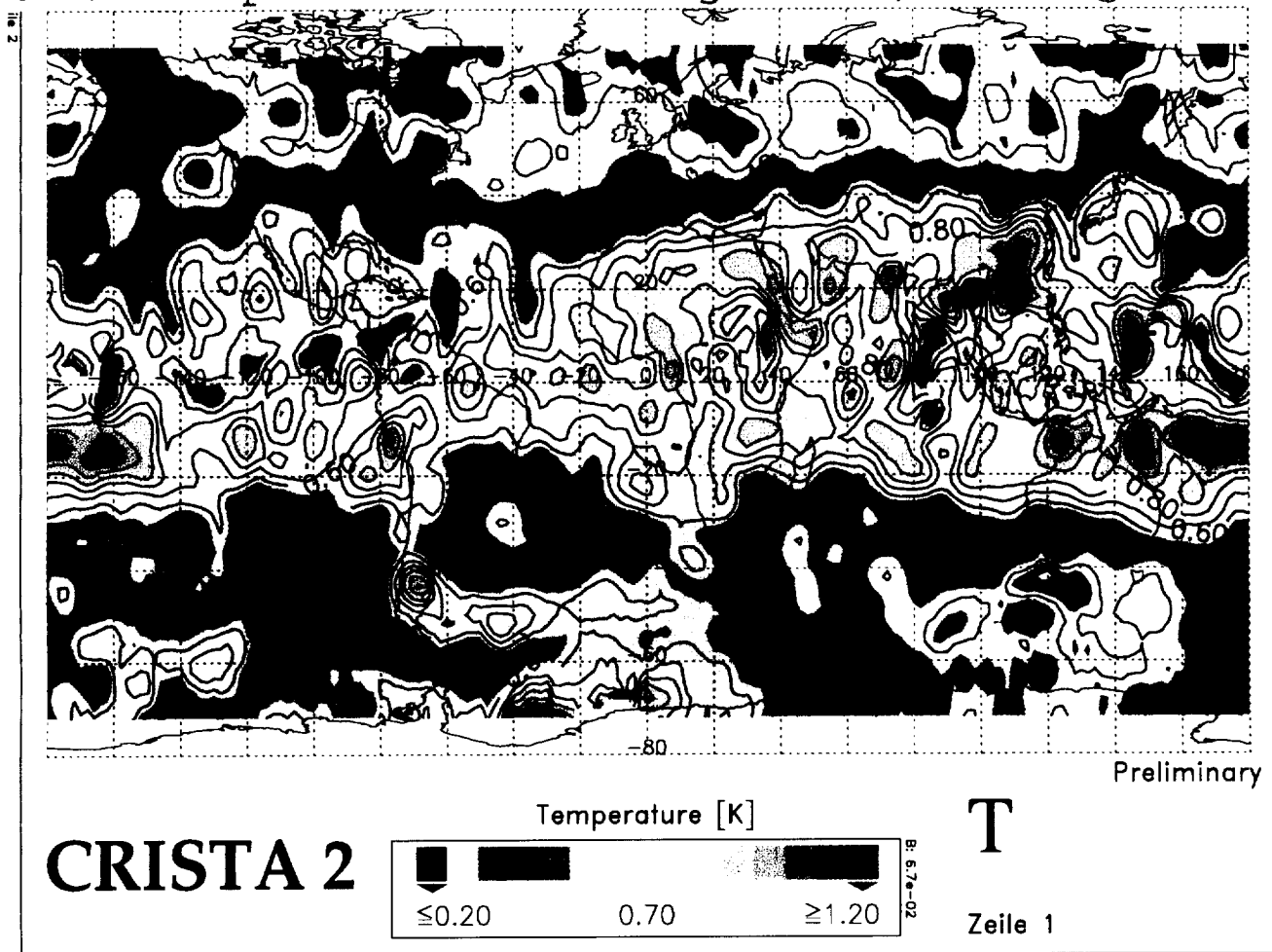


Figure 1: Plot of global small-vertical-scale temperature variance at 23 km during 9-13 August, 1997, inferred from CRISTA data during the second CRISTA-SPAS mission (STS-85).

Ocean to the east of South America.

1.2 Global Modeling of Gravity Wave Activity during the CRISTA Missions

¹ see the CRISTA homepage, at <http://www.crista.uni-wuppertal.de>.

² see <http://titania.osf.hq.nasa.gov/shuttle/sts66/spas.html> for a full description of the first CRISTA-SPAS mission.

Modeling of gravity wave activity during the CRISTA missions continued this month. The methodology and data

Climatology of Transmitted Horizontal Wavelengths

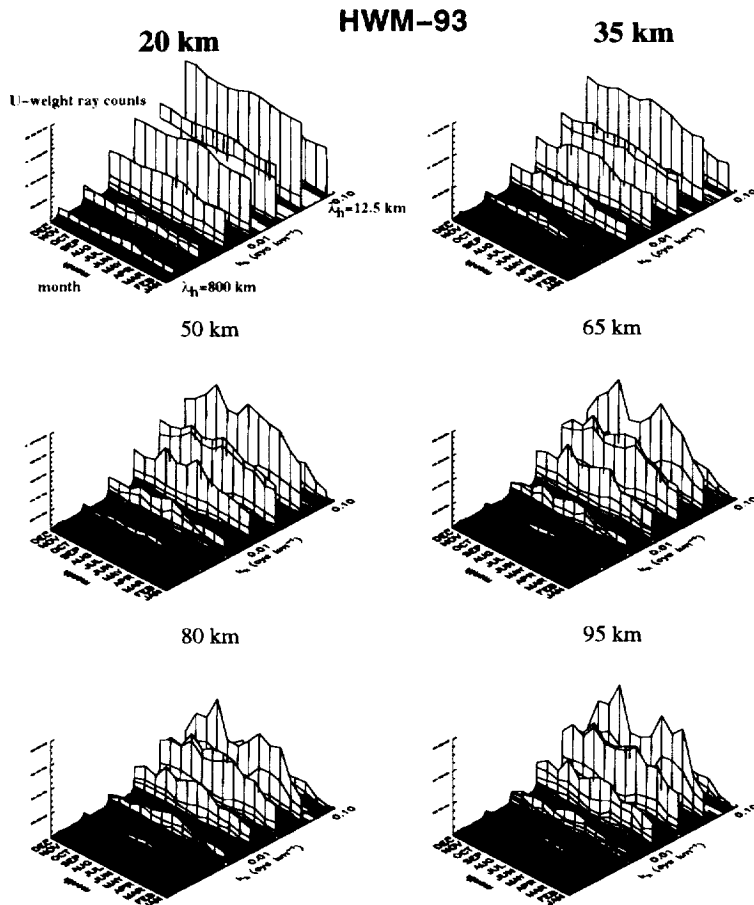


Figure 2: Histograms of gravity wave horizontal wavelength abundances as a function of month and height. Results come from GROGRAT simulations using the HWM-93 wind and temperature climatology [Hedin *et al.*, 1996], using isotropic globally-uniform source spectrum of waves.

suggests that earlier indications of longitudinal variability in the gravity wave activity in the Northern Hemisphere may be partly real, rather than purely a function of the filtering effect of the observations [Alexander, 1998]. This has raised the question as to whether the geographically variable mountain wave forcing that occurs in the Northern Hemisphere may be impacting these observed MLS gravity wave morphologies. The analysis is preliminary but, if it holds up, we shall initiate mountain wave simulations to assess these possibilities. Work also continues with Dr. Greg Fall at the University of Michigan, in using GROGRAT simulations to assess and characterize possible gravity wave signatures in HRDI nightglow data, which he is analyzing.

1.4 Climatological Simulations of Mesospheric Gravity Wave Activity for Comparisons with Gravity-wave Data Inferred from UARS Data

Work continued from the first quarter report, on using GROGRAT to simulate mesospheric climatologies of gravity waves using winds and temperatures from the 1993 version of the Horizontal Wind Model (HWM-93) [Hedin *et al.*, 1996]. The simulation methodology and parameters are as described in the earlier quarterly report. Some of the results are being replotted and reanalyzed for inclusion in the paper of Eckermann *et al.* [1998]. For example, Figure 2 shows histograms of the number of gravity wave horizontal wavelengths as a function of month of the year and height, as derived from these GROGRAT simulations through the HWM-93 reference atmosphere. The results show a preferential transmission of waves in the 25-100 km range, and interesting reproducible seasonal variations in these transmission characteristics. Such findings are extremely useful for predicting what the spatial scales of the dominant mesospheric waves might be, and whether various spaced-based sounding methods can resolve them explicitly.

sources are the same as those described in the previous quarter's report, where preliminary results for the first mission were presented. Dr. Eckermann presented these modeling results, as well as preliminary data from the first mission (e.g. Plate 1 of previous quarter's report), in an invited oral presentation at the DYSMER³ Symposium in Kyoto, March 15-20, 1998. An invited paper is also being prepared for a special DYSMER issue of the journal *Earth Planets and Space*.

Given the new results generated during this quarter for the second CRISTA mission, corresponding simulations were devised and performed for gravity wave activity during the second mission period. Plate 1 shows simulated activity during three successive days (8-10 August, 1997) of the second mission. We note that strong mountain wave activity is simulated near the southern tip of South America, as seen in the data for the second mission in Figure 1. Eckermann [1998] presented these results in an invited presentation⁴ at the Spring Meeting of the American Geophysical Union in May.

1.3 Preliminary Analysis of UARS-Derived Gravity Wave Products

Work continued this quarter on the collaborative analysis of data from other UARS instruments. Scientific discussions continued with Dr. Charles McLandress of his further analysis of the MLS gravity wave product. In particular, McLandress' analysis

³ <http://www.kurasc.kyoto-u.ac.jp/radar-group/psmos/DYSMER/>

⁴ Paper A32D-08: see <http://www.agu.org/meetings/sm98top.html>

Collaborations also continue with Dr. Valery Yudin at the State University of New York (SUNY) at Stony Brook in interfacing their assimilated models of UARS-derived mean winds and tidal structures with GROGRAT, to look at the possible impact of tidal modulation on global gravity-wave climatologies.

1.4 Simulations of Gravity Wave Measurements from Space-based Platforms like UARS

Work also continued this month in developing both the theory and models that are needed to study just how satellite-based instruments detect and resolve gravity waves. Significant progress was made this month using a new model of space-based observations of gravity wave using the CRISTA limb-scanning instrument. The model sets up a simple linear gravity wave train in two-dimensional (x - z) space, then simulates a limb scan through this structure. A series of such simulations give estimates of the sensitivity or "visibility" of CRISTA to gravity wave oscillations of various wavelengths. It is found that the curved ray paths of radiation through a limb scan can lead to a rather complex non-uniform profiling of waves. This profiling can be phase preferential for certain waves – i.e., the radiation ray path can lie nearly parallel to wave phase fronts over a significant fraction of the ray path - thus making the instrument somewhat more sensitive to certain types of waves. A range of these types of simulations have verified that CRISTA is sensitive to vertical wavelengths > 5 -10 km. Dr. Peter Preusse will present this work at the international COSPAR conference in Nagoya, Japan. A paper on the technique, as well as the first observational results (section 1.1), is also being prepared for *Advances in Space Research* [Preusse et al., 1998].

2. Analysis

2.1 Interpretation of Results Obtained to Date

The modeling, both climatological and "event oriented," continues to simulate features that have much in common with the data from UARS and CRISTA-SPAS. The expansion of the analysis this quarter to both the extraction and modeling of gravity wave activity during the second CRISTA-SPAS mission (7-16 August, 1997) has tended to confirm some tentative findings based on last quarter's analysis and modeling of data from the first mission (3-14 November, 1994). In particular, the strong bursts of activity near the southern tip of South America, observed in the first mission's data, also appear in data from the second mission. Furthermore, the GROGRAT-NRL/MWFM simulations for the second mission also predict such activity as due to the stratospheric penetration of mountain waves forced by flow over the southern Andes, as they did for the same features in the first mission. The weight of this accumulated observational and modeling evidence strongly suggests that these features of the data are generated by stratospheric mountain waves.

The simulated mesospheric climatologies continue to provide interesting insights. For example, the climatologies of transmitted horizontal wavelengths show preferential values ~ 50 km (Figure 2), which agree with accumulated observational results from several ground-based sites [e.g., Reid, 1986; Manson, 1990]. Similar results for transmitted ground-based phase speeds and wave amplitudes also resemble similar collated data from ground-based stations.

2.2 Recommended Further Action

The analysis of the CRISTA data clearly indicates that gravity waves can be resolved by the instrument [Preusse et al., 1998] and the simulations appear to present a persuasive case that the persistently-observed activity near the tip of South America is due to mountain waves [Eckermann et al., 1998]. The equatorial activity is more problematic. Preliminary simulations indicate that nonstationary phase speeds propagate very efficiently into the equatorial stratosphere. The origin of such waves is very likely to be convection. Parameterization of this source is much more difficult, since it is an intrinsically variable weather-related phenomenon, and the generation of gravity waves via convective latent heat release is not well understood. We will continue to work on developing idealized methods to characterize nonstationary wave sources, in an attempt to better model and understand the strong equatorial wave activity observed in CRISTA.

Significant progress was made in understanding the way CRISTA resolves gravity waves [Preusse et al., 1998]. Similar studies have been applied to the MLS gravity wave product [e.g., Wu and Waters, 1997; Alexander, 1998]. The next step seems to be to study and intercompare the "visibility" characteristics of each instrument in a careful and systematic manner. This may help to explain some of the differences in wave activity inferred from both instruments. For example, it has been noted that the MLS gravity-wave product does not contain much activity in tropical regions, whereas strong activity is observed in the equatorial belt in the CRISTA data (see, e.g., Figure 1).

2.3 Relation to Ultimate Objectives of the Research Contract

The work outlined to date in section 1 represents further significant progress in all areas of the proposed contract research (see section 2 of the original proposal). The analysis to date strongly suggests that mountain waves are being observed in the stratosphere over the tip of South America. This region is close to the Antarctic Peninsula, where stratospheric mountain waves often precipitate formation of polar stratospheric clouds (PSCs) and consequent ozone destruction in ever-expanding zones around the PSCs [e.g. Cariolle et al. 1989]. Ozone depletion and concomitant increases in the intensity of surface-level ultra-violet radiation (UV) has also been cited in many important biological problems impacting southernmost South America (e.g., increased sheep blindness; declining frog populations). The suggestion here is that stratospheric

mountain waves exist over southern South America too. Thus, a north-south “line” of heightened susceptibility to mountain wave activity appears to extend from the Antarctic Peninsula up to South America, which may generate PSCs and similar lines of ozone destruction. Even if this is not so, the adiabatic uplift of air associated with mountain waves over South America is known to decrease ozone densities locally [e.g., Danilov *et al.*, 1995], which will also increase the transmission of ultraviolet radiation to the ground.

Such findings are early and speculative. Data analysis and interpretation using both UARS and CRISTA-SPAS data may clarify them, and/or lead to other interesting findings, much as set out in the original research proposal.

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Amplitude-Weighted Ray Counts: $z=25$ km

All Mountain Waves

Waves $\lambda_z > 10$ km only

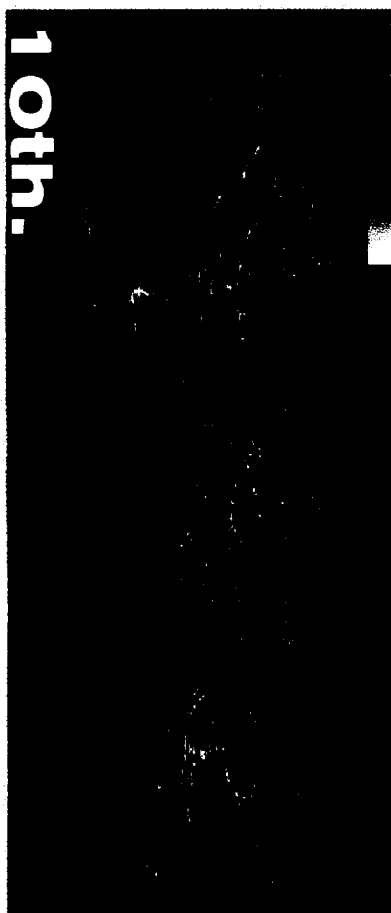
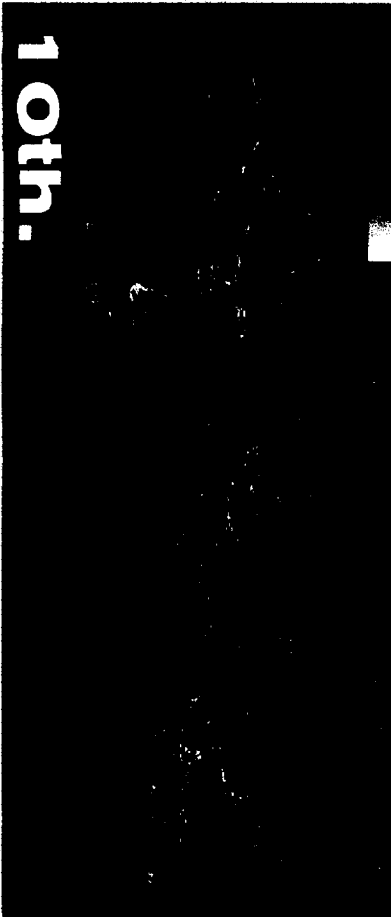
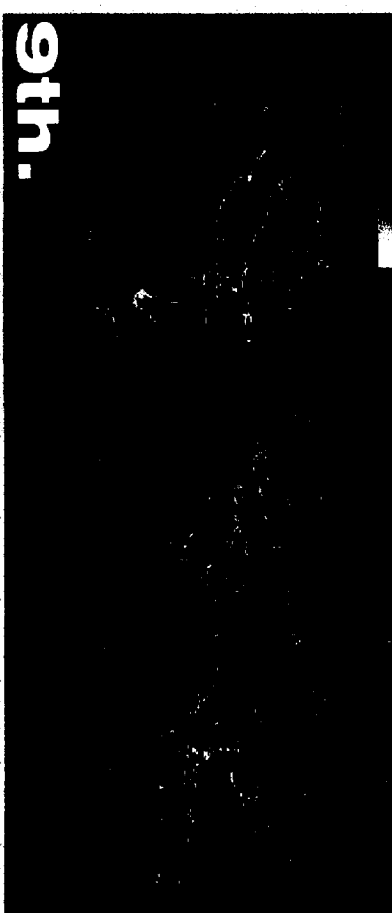
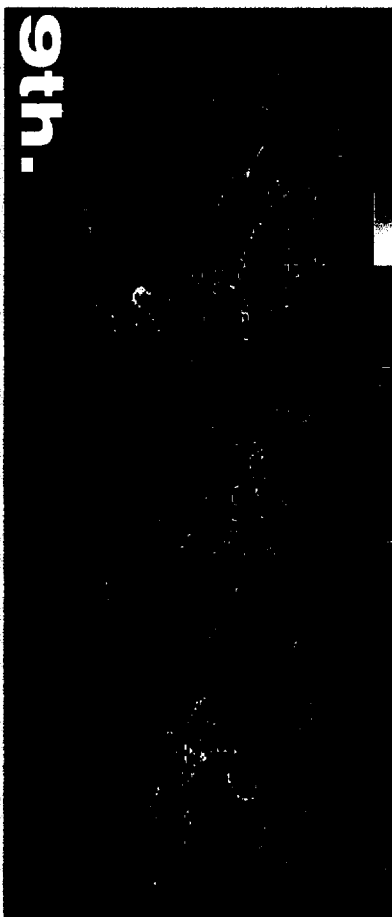
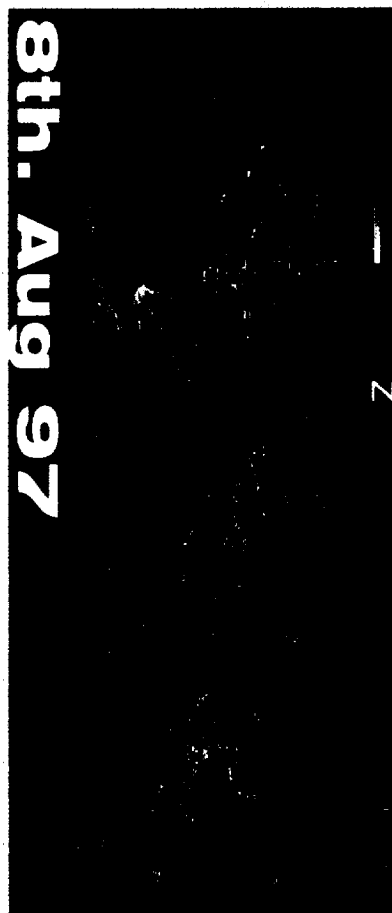
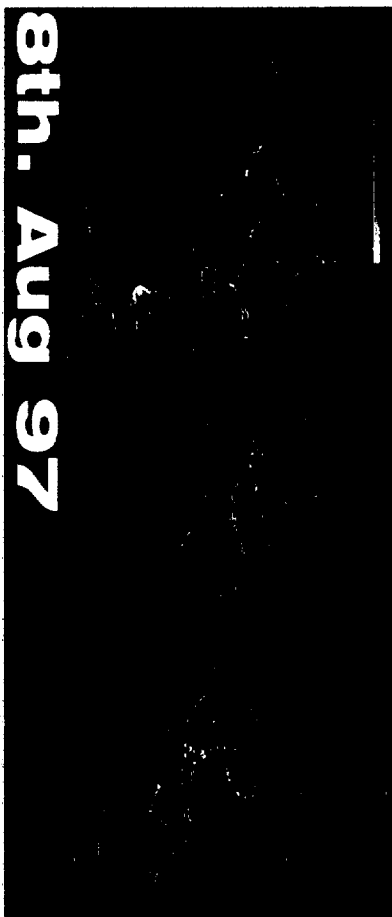


Plate 1: Simulations of mountain wave activity during three successive days of the second CRISTA mission (8-10 August, 1997), as simulated using the Gravity-wave Regional or Global Ray Tracer (GROGRAT) and the NRL Mountain Wave Forecast Model (NRL/MWFM). Plots on left show all activity, plots on right show results after retention of waves with $\lambda_z > 10$ km, which mimics the filtering effect of the CRISTA limb scan [Preusse et al. 1998].

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13. ABSTRACT (Maximum 200 words) Progress in research into the global morphology of gravity wave activity using UARS data is described for the period March-June, 1998. Highlights this quarter include further progress in the analysis and interpretation of CRISTA temperature variances; model-generated climatologies of mesospheric gravity wave activity using the HWM-93 wind and temperature model; modeling of gravity wave detection from space-based platforms. Preliminary interpretations and recommended avenues for further analysis are also described.					
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